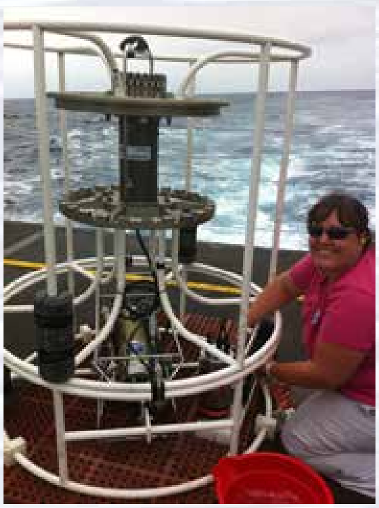
Lesson 7: The Oceanographic Yo-yo



A conductivity/temperature/depth (CTD) sensor package. Image courtesy of NOAA *Okeanos Explorer* Program. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/july16/media/ctd.html*

Focus

CTD (conductivity, temperature, depth profiler), ocean chemistry and hydrothermal vents

Grade Level

7-8 (Physical Science)

Focus Question

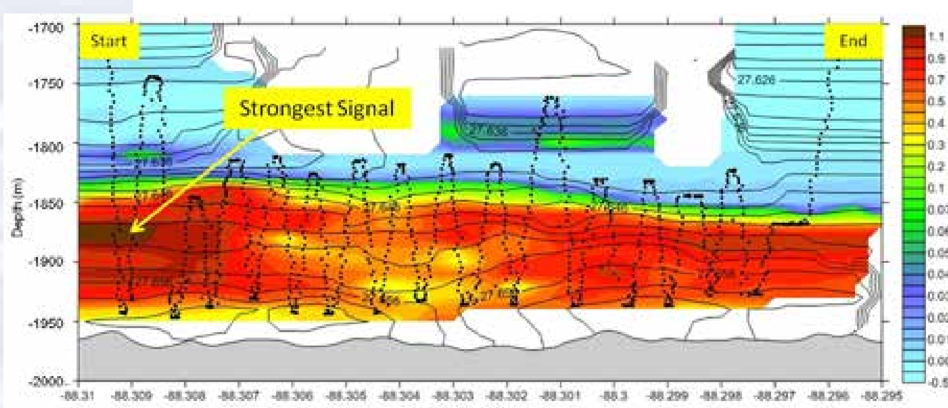
How do ocean explorers aboard the *Okeanos Explorer* use chemical clues to locate hydrothermal vents in the deep ocean?

Learning Objectives

- Students will analyze and interpret data from the *Okeanos Explorer* to make inferences about the possible presence of hydrothermal vents.
- Students will explain how interaction with hydrothermal vents affects chemical and physical properties of seawater.

Materials

- One gallon of water, chilled in a refrigerator
- Vinegar; 1 tablespoon for each student group
- A heat source (microwave oven or hot plate)
- One eyedropper
- One tablespoon
- For each student group:
  - Copy of *CTD Sample Analysis Worksheet*
  - Two thermometers
  - 5 strips wide range (approximate pH 2-9) pH paper with color chart
  - Five 100ml beakers or plastic cups labeled A, B, C, D, and E



This is a plot of the data from a CTD tow. The x axis displays the longitude of the tow, the vertical axis is depth, and the shading along the tow is the Light Scattering Sensor data. The dark patch on the left (beginning of tow) is the strongest plume signal. Image courtesy of NOAA *Okeanos Explorer* Program. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/tow01_results_diagram_hires.jpg*

Audio Visual Materials

- Video projector or large screen monitor for showing downloaded images (see Learning Procedure, Step 2)

Teaching Time

Two 45-minute class periods

Seating Arrangement

Groups of three to four students

Maximum Number of Students

30

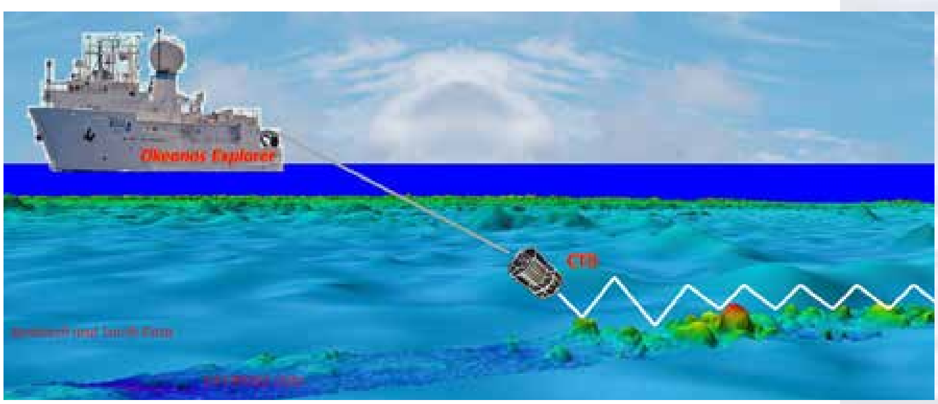
Key Words and Concepts

Ocean Exploration
Okeanos Explorer
CTD
Conductivity
pH
Hydrothermal vent
Plume

Background

For discussion about the exploration strategy used aboard the *Okeanos Explorer*, please see the *Introduction to Volume 2: Why Do We Explore* beginning on page 9. For background about CTD instruments, please see the *Introduction to Water Quality Investigations* on page 87.

Temperature measurements from CTD sensors can be used to detect changes in water temperature that may indicate the presence of volcanoes or hydrothermal vents. Masses of seawater with unusual characteristics are called plumes, and are usually found within a few hundred meters of the ocean floor. Since underwater volcanoes and hydrothermal vents may be several thousand meters deep, ocean explorers often raise and lower a CTD rosette through several hundred meters near the bottom as the ship slowly cruises over the area being surveyed. This repeated up-and-down motion of the towed CTD may resemble the movement of a yo-yo; a resemblance that has led to the nickname "tow-yo" for this type of CTD sampling.



This image demonstrates the concept of a CTD Tow-Yo. The CTD is lowered to within 20 meters of the seafloor, and then is cycled between near-bottom and 300 meters above the seafloor (like a yo-yo) as it is towed behind the ship. Sensor data is recorded and monitored continuously to look for signs that plumes from hydrothermal vents are present. Image courtesy of NOAA *Okeanos Explorer* Program.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/tow_yo_diagram_hires.jpg

This lesson introduces students to simple analysis of CTD data as a method for finding underwater volcanoes and hydrothermal vents.

Learning Procedure

1. To prepare for this lesson:
   a) Review:
      - Introductory essays for the INDEX-SATAL 2010 Expedition (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html*);
      - Background information on CTD technology at *http://www.pmel.noaa.gov/vents/PlumeStudies/WhatIsACTD/CTDMethods.html*

   (b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.

   (c) If students are not familiar with deep-sea chemosynthetic communities, you may want to use Multimedia Discovery Mission Lesson 5, Chemosynthesis and Hydrothermal Vent Life (*http://oceanexplorer.noaa.gov/edu/learning/welcome.html*), and/or information from *http://www.pmel.noaa.gov/vents/nemo/explorer.html*.

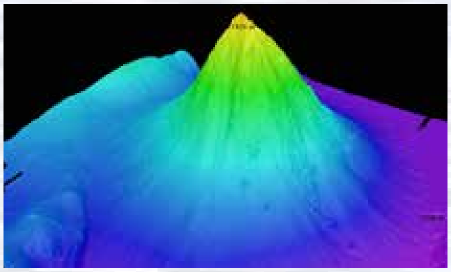
   (d) Review procedures for the simulated analysis of CTD samples (Step 4). Prepare materials for this activity:
      1) Chill one gallon of water overnight in a refrigerator.
      2) For each group of four students, fill five 100ml beakers with chilled water and label each with an A, B, C, D and E.
      3) Heat the water in all beakers labeled D for 60 seconds in the microwave oven about 15 minutes before the start of class. The water should be above 50°C, but not boiling.
      4) Add 3 drops of vinegar to all beakers labeled C and E and stir.
      5) Add one tablespoon of vinegar to all beakers labeled D and stir.

   (e) If desired, download images referenced in Step 2.

2. Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition. Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf*). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:
   - The overall strategy is based on finding anomalies;
   - This strategy involves
     - Underway reconnaissance;
     - Water column exploration; and
     - Site characterization;
   - This strategy relies on four key technologies:
     - Multibeam sonar mapping system;
     - CTD and other electronic sensors to measure chemical and physical seawater properties;
     - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters; and
     - Telepresence technologies that allow people to observe and interact with events at a remote location.

   You may want to show some or all of the images in the adjacent sidebar to accompany this review.

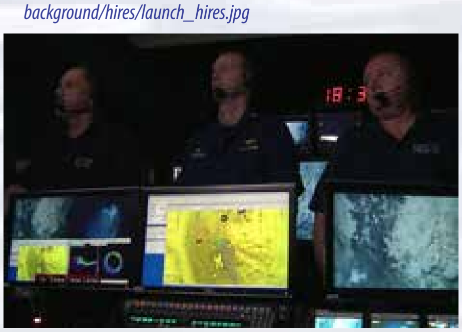
   Show an image of a CTD, and explain that this is actually a collection of several electronic instruments that measure various things about seawater. The basic instruments measure temperature, depth, and conductivity. Most of the device



Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg

A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.
http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html

Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

seen in the image is a water sampling device called a rosette or carousel, that contains water sampling bottles that are used to collect water at different depths. Before the rosette is lowered into the ocean, the bottles are opened so that water flows freely through them. As the rosette travels through the water column, scientists can monitor readings from the CTD sensors. If something unusual appears in the measurements, the scientists can send a signal through the CTD cable that closes one or more of the bottles to collect a water sample from the location where the unusual measurements appeared.

If students are not familiar with deep-sea chemosynthetic communities, briefly describe the concept of chemosynthesis, and contrast it with photosynthesis. Tell students that chemosynthetic ecosystems in the deep ocean are found where a source of chemical energy is emerging from the ocean floor. If you have decided to use materials referenced in Step 1c, present these now. Tell students that a major objective of the INDEX-SATAL 2010 Expedition was to locate submarine volcanoes, hydrothermal vents, chemosynthetic ecosystems, and seamounts associated with active geologic processes in Indonesia's deep sea.

3. Discuss some of the clues that might result from the interaction of hydrothermal vents with seawater. Increased temperature is fairly obvious, since heat from Earth's core is the energy source that causes vents to form. Temperatures of hydrothermal fluids may be more than 300°C, since the high pressure of deep-sea environments prevents water from boiling. Fluids from hydrothermal vents are often highly acidic, in contrast to normal seawater which is slightly basic; so pH is another potential clue. You may need to explain that pH is a measure of the concentration of hydrogen ions. For a more detailed discussion about pH, please see the lesson, *Why Do We Explore?* (*http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09whydoweexplore.pdf*). Hydrogen sulfide is often found in hydrothermal vent fluids, but is not normally found in seawater. So a chemical analysis that indicates its presence in a seawater sample would be another clue that signals vents may be nearby.

4. The following activity simulates an analysis of water samples collected by a CTD. Tell students that their assignment is to analyze several samples collected by a CTD to determine whether any of the samples suggest that they might have been collected from a location near a hydrothermal vent. Demonstrate the correct way to measure pH with a pH strip if students are not already familiar with this procedure.

   Provide each student group with two thermometers, 5 strips of pH paper, a pH color indicator chart, a *CTD Sample Analysis Worksheet*, and samples A, B, C, D and E. Tell students to make measurements needed to complete the worksheet on page 108 and to plot the CTD data on the graphs provided on pages 109-110.

   Be sure students understand that the grids provided for their graphs have zero at the TOP of the y-axis. This is because oceanographers like to plot CTD data with depth on the y-axis and the greatest depths at the bottom of the plot, since that is the way we usually think about a profile of the water column.

5. Discuss students' results. Students should infer that sample D may have been collected in the vicinity of a hydrothermal vent, since its temperature is noticeably higher than that of the other samples, and its pH is noticeably lower. Ask students

A closeup of a CTD, the primary tool used to map hydrothermal plumes. A ring of plastic sampling bottles surrounds the CTD, which is housed in the steel container in the center of the rosette. CTD sensors are visible at the bottom of the pressure case. Image courtesy of NOAA Vents Program.
http://oceanexplorer.noaa.gov/explorations/12fire/background/hires/ctd_closeup_hires.jpg

Figure 1.

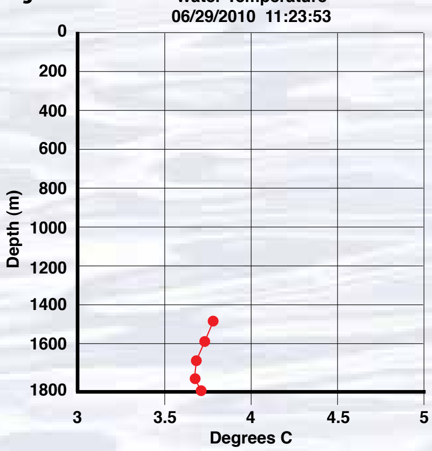


Figure 2.

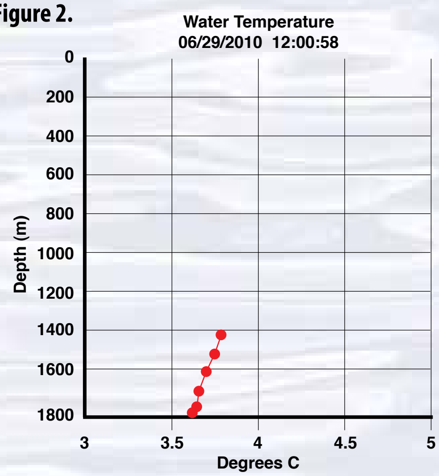
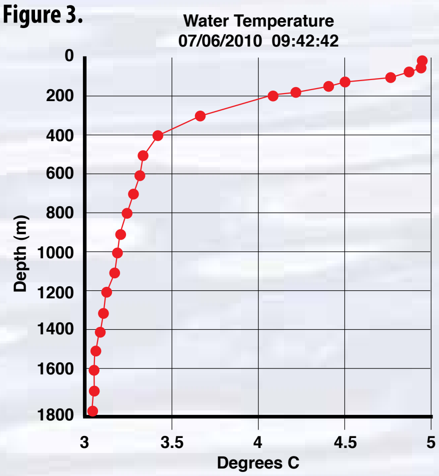


Figure 3.



Note: Graphs of temperature and other CTD data collected during *Okeanos Explorer* cruises in 2010.

what other measurements might be made to support this inference. These might include chemical analysis to detect the presence of substances associated with hydrothermal vents, such as hydrogen sulfide.

Students' graphs of CTD data should resemble Figures 1, 2, and 3. Students should recognize that Figure 1 is different from the others, in that water temperature increases near the bottom (even a small increase is significant). Since this is not what would ordinarily be expected, it is an anomaly! In fact, this CTD cast was made in the vicinity of an active hydrothermal vent. The next day, *Okeanos Explorer*'s ROV *Little Hercules* visited the site and found an active hydrothermal vent "surrounded by yellow and black molten sulfur, multiple species of hot-vent shrimp, a 10 cm scale worm, and a small patch of stalked barnacles. After departing from the vent, the ROV ascended the summit ridge and encountered fields of sulfide chimneys with vast aggregations of stalked barnacles at their base. The chimneys varied in terms of age and venting characteristics. Some chimneys were fairly oxidized and others covered in white sulfide. Some chimneys were venting clear fluid while others were venting black smoke." You can read more about the site, and see images from *Little Hercules* here: *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june30/june30.html*.

Point out that this is an excellent example of the interdependence of science, engineering, and technology. The instrument technologies produced by engineering made it possible to make measurements that detected an anomaly. Other technologies made it possible to investigate the anomaly and provide scientific data from a new hydrothermal vent site.

6. Discussion of CTD technology may also include the following components of technological literacy (ITEA, 2007):
   - **Scope of technology –** Development of CTD instrumentation allows many chemical and physical characteristics to be measured in the ocean, some of which could not be measured in deep water before this technology was created.
   - **Core concepts of technology –** A CTD is an example of several technological systems connected together; including different systems to measure various chemical and physical characteristics of seawater, and equipment for collecting water samples from very deep areas in Earth's ocean.
   - **Relationships between technologies and other fields of study –** Improvements to each of the technologies listed above improves the overall capability of water column investigations; and this information is useful to geologists, biologists, and many other branches of science.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics" in the menu on the left side of the page, then "Habitats" then select "Deep Sea" for activities and links about deep-ocean ecosystems.

The "Me" Connection

Have students read the daily log entry for July 29, 2010 from the INDEX-SATAL 2010 Expedition (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july29/july29.html*), and write a brief essay discussing whose job they would like to have if they were personally aboard the ship.

Connections to Other Subjects

English Language Arts, Social Studies, Mathematics

Assessment

Class discussions and students' work with the charting activity provide opportunities for assessment.

Extensions

Visit the Web page (*http://oceanexplorer.noaa.gov/okeanos/welcome.html*) for reports, images, and other products from *Okeanos Explorer* cruises.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html – Click on the links to Lessons 1, 5, and 6 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

And Now for Something Completely Different…

(from the 2005 GalAPAGos: Where Ridge Meets Hotspot Expedition)

http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_dfferent.pdf

Focus: Biological communities at hydrothermal vents (Grades 5-6; Life Science)

Students identify and describe organisms typical of hydrothermal vent communities near the Galapagos Spreading Center, explain why hydrothermal vent communities tend to be short-lived, and identify and discuss lines of evidence which suggested the existence of hydrothermal vents before they were actually discovered.

A Hydrothermal AdVENTure

(from the INSPIRE: Chile Margin 2010 Expedition)

http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/aydrothermal.pdf

Focus: Hydrothermal vents (Grades 5-6; Earth Science)

Students explain the overall structure of hydrothermal vents and how they are related to the motion of tectonic plates, and create a model of a hydrothermal vent.

The Volcano Factory

(from the 2004 Submarine Ring of Fire expedition)

http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF.volcanism.pdf

Focus: Volcanism on the Mariana Arc (Grades 5-6; Earth Science)

Students explain the tectonic processes that result in the formation of the Mariana Arc and the Mariana Trench, and explain why the Mariana Arc is one of the most volcanically active regions on Earth.

Unexplored!

(from the New Zealand American Submarine Ring of Fire 2005 Expedition)
http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_unexplored.pdf

Focus: Scientific exploration of deep-sea volcanoes (Grades 5-6; Life Science/Physical Science/Earth Science)

Students compare and contrast submarine volcanoes at convergent and divergent plate boundaries; infer the kinds of living organisms that may be found around hydrothermal vents; describe three ways in which scientists may prepare to explore areas that are practically unknown; and explain two types of primary production that may be important to biological communities around hydrothermal vents in the Mariana Arc.

Living With the Heat

(from the Submarine Ring of Fire 2006 Expedition
http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.LivingHeat.pdf

Focus: Hydrothermal vent ecology and transfer of energy among organisms that live near vents (Grades 5-6; Life Science/Earth Science)

Students describe how hydrothermal vents are formed and characterize the physical conditions at these sites; explain what chemosynthesis is and contrast this process with photosynthesis; identify autotrophic bacteria as the basis for food webs in hydrothermal vent communities; and describe common food pathways among organisms typically found in hydrothermal vent communities.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/hdwe_ngss.pdf*

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We value your feedback on this lesson, including how you use it in your formal/informal education settings. Please send your comments to:
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Acknowledgments

Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC. Design/layout: Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: *http://oceanexplorer.noaa.gov*

CTD Sample Analysis Worksheet

Group Name: ____________________

Sample	Temperature	pH
A		
B		
C		
D		
E		

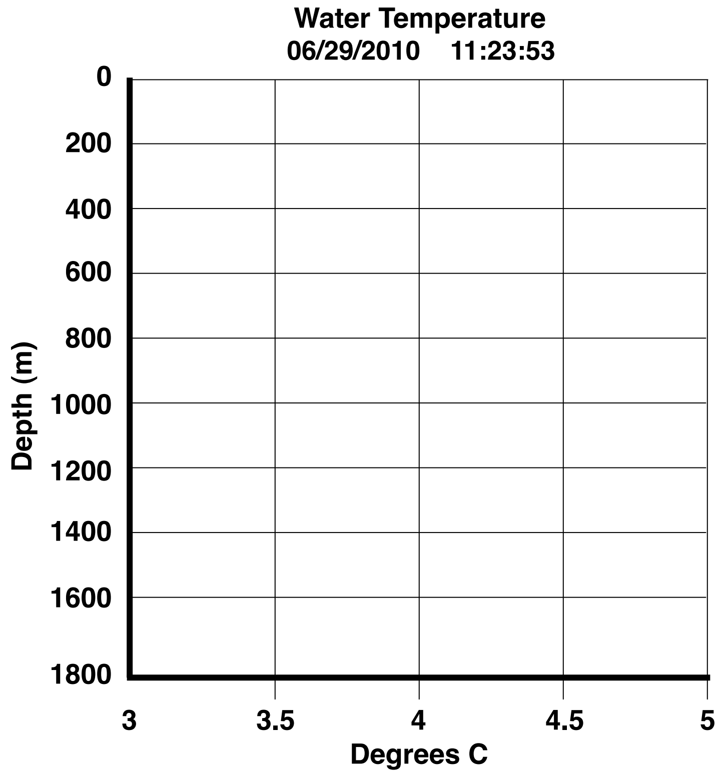
1. Do the data in the table above suggest that any of these samples might have been collected near a hydrothermal vent?

2. How do your data support this inference?

3. Here are some data from CTD casts made aboard the *Okeanos Explorer* during the INDEX-SATAL 2010 Expedition (these are just a few of the data points provided by the CTD instruments; the complete data sets contain thousands of points!). Plot these points on the grids. Do any of your graphs show any possible anomalies?

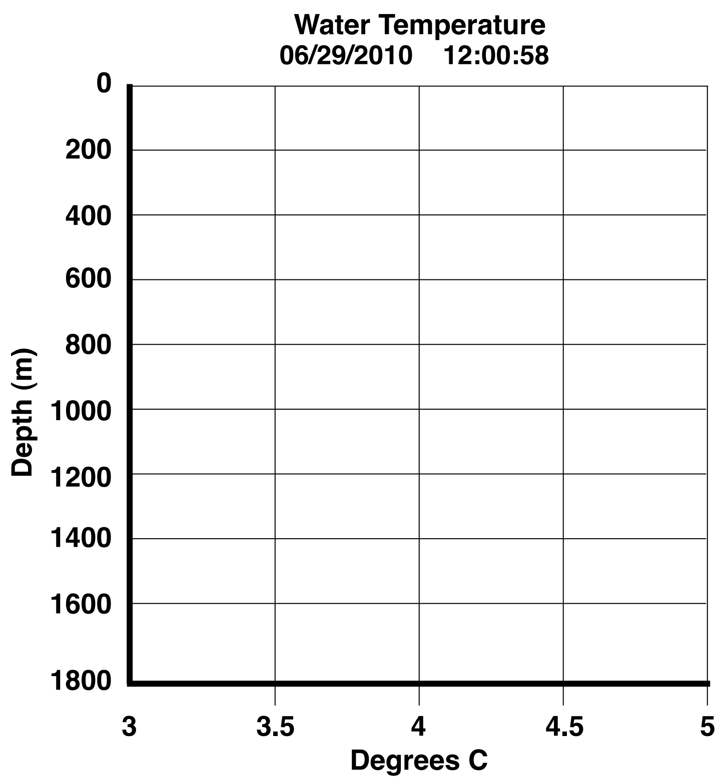
CTD Cast 06/29/2010 11:23:53

Depth (m)	Water Temperature (°C)
1450	3.8
1600	3.75
1680	3.6
1750	3.6
1800	3.7



CTD Cast 06/29/2010 12:00:58

Depth (m)	Water Temperature (°C)
1400	3.8
1500	3.75
1600	3.7
1700	3.67
1750	3.65
1800	3.6



CTD Cast 07/06/2010 09:42:42

Depth (m)	Water Temperature (°C)
10	4.95
50	4.9
80	4.85
100	4.8
150	4.5
175	4.4
190	4.2
200	4.1
300	3.7
400	3.4
500	3.35
600	3.32
700	3.30
800	3.25
900	3.20
1000	3.175
1100	3.16
1200	3.15
1300	3.12
1400	3.10
1500	3.08
1600	3.07
1700	3.06
1800	3.05